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SILICON SOLAR CELL AS A HIGH-SOLAR-INTENSITY RADIOMETER

by Ernie W. Spisz and Ronald R. Robson

Lewis Research Center
Cleveland, Ohio 44135

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16. Abstract

The characteristics of a conventional, 1- by 2-cm, N/P, gridded silicon solar cell when used as a radiometer have been determined for solar intensity levels to 2800 mW/cm^2 (20 solar constants). The short-circuit current was proportional to the radiant intensity for levels only to 700 mW/cm^2 (5 solar constants). For intensity levels greater than 700 mW/cm^2, it was necessary to operate the cell in a photoconductive mode in order to obtain a linear relation between the measured current and the radiant intensity. When the solar cell was biased with a reverse voltage of -1 V, the measured current and radiant intensity were linearly related over the complete intensity range from 100 to 2800 mW/cm^2.

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SUMMARY

The characteristics of a conventional 1- by 2-centimeter N/P gridded silicon solar cell when used as a radiometer have been determined for solar intensity levels to 2800 milliwatts per square centimeter (20 solar constants). The short-circuit current was proportional to the radiant intensity for levels only to 700 milliwatts per square centimeter (5 solar constants). For intensity levels greater than 700 milliwatts per square centimeter, it was necessary to operate the cell in a photoconductive mode in order to obtain a linear relation between the measured current and the radiant intensity. When the solar cell was biased with a reverse voltage of -1 volt, the measured current and radiant intensity were linearly related over the complete intensity range from 100 to 2800 milliwatts per square centimeter.

INTRODUCTION

The silicon solar cell is frequently used as a radiometer for many routine engineering measurements where visible radiant energy must be measured or controlled (refs. 1 and 2). This type of solar cell is ideally suited for many such applications. It is inexpensive, accurate, repeatable, stable, and fast-responding. If the solar cell is operated properly, the short-circuit current (or a close approximation thereof) approximates the light-generated current and can be linearly correlated with the radiant intensity level. However, for high-intensity levels (greater than about 300 mW/cm^2) the short-circuit current may no longer be a close approximation to the light-generated current, and care must be exercised in using the solar cell as a radiometer (ref. 3). The nonlinearity occurs because internal series resistance (ref. 3) and temperature effects (ref. 2) become important at high-intensity levels.

The occasion to measure and control solar radiation at high-intensity levels occurred when the carbon arc simulator of reference 4 was modified to provide solar radiation at intensity levels up to 2800 milliwatts per square centimeter. A conventional

1- by 2-centimeter, water-cooled, silicon solar cell had been used for a number of years to measure accurately and control the output from that simulator over the intensity range from 2 to 200 milliwatts per square centimeter. It was desirable, therefore, to utilize the experience which has been gained and also the existing radiometer and radiant-intensity control system for the high-intensity simulator also. The fact that the short-circuit current tends to become nonlinear at the high-intensity levels and introduces control problems prompted this study of the characteristics of silicon solar cells at high radiant intensities. Reference 5 indicates that the nonlinear problems associated with the solar cell could be alleviated by operating the cell in a photoconductive rather than a photovoltaic mode, that is, by measuring the cell current when a reverse bias voltage is imposed across the cell. With sufficient reverse bias the measured current is a better approximation to the light-generated current than is the short-circuit current and would be more nearly linearly related to the radiant intensity.

The characteristics of a conventional water-cooled solar cell as they pertain to the application of the solar cell as a radiometer are presented in this report. Both the photovoltaic and photoconductive electrical characteristics are presented for the radiant intensity range from 70 to 2800 milliwatts per square centimeter. The effect of the temperature of the cooling water used to cool the solar cell is also presented for water temperatures from 12° to 90° C.

APPARATUS AND PROCEDURE

The optical system of the carbon arc solar simulator of reference 4 was modified and used to provide solar intensities for the range from 70 to 2800 milliwatts per square centimeter in order to obtain the electrical characteristics of a conventional 1- by 2-centimeter, N/P, gridded, silicon solar cell. The solar cell was mechanically mounted to a copper block which was water-cooled by a recirculating water supply system. The water temperature could be accurately controlled over the temperature range from 12° to 90° C.

The electrical characteristics of the solar cell were obtained with the operational amplifier circuit shown schematically in figure 1. The measuring circuit consists of a four-wire system which provides a high-impedance loop for voltage measurement and a current-carrying loop for cell loading and current measurement. Current-voltage characteristics curves were obtained by varying the output of the constant-voltage power supply with the operational amplifier acting as the circuit load.

The reference radiant intensity measurements were made with a water-cooled pyrheliometer which had been calibrated up to 1400 milliwatts per square centimeter. The linearity of the pyrheliometer was further verified for radiant intensity levels up to

3000 milliwatts per square centimeter by comparative measurements against another calibrated radiometer which was operated at more appropriate low-intensity levels by using attenuating filters.

RESULTS

The most important characteristic of a radiometer is the relation between the measured output and the radiant intensity. For a solar cell the measured output is generally the short-circuit current. Figure 2 presents a comparison of the cell current with radiant intensity levels for the intensity range from 70 to 2800 milliwatts per square centimeter. The nonlinearity of the short-circuit current illustrates the primary difficulty encountered in using a silicon solar cell (even a water-cooled one) as a radiometer at the higher intensity levels. The short-circuit current departs from linearity at an intensity level of 700 milliwatts per square centimeter. At a level of 2800 milliwatts per square centimeter the short-circuit current is 35 percent less than the value obtained by a linear extrapolation from the correlation obtained at the lower intensity levels. Also included in figure 2 is the measured circuit current for the solar cell biased at a voltage of -1 volt. The current with a -1-volt bias voltage closely approximates the light-generated current and is directly proportional to the radiant intensity over the complete range covered. When the cell is operated in the photoconductive rather than the photovoltaic mode, the measured solar-cell current has the desired linear characteristics required for application as an accurate radiometer. The correlation of the photoconductive current with radiant intensity that is shown in figure 2 is repeatable and has been stable over a period of 6 months.

The reason the photoconductive current is more linearly related to the radiant intensity than is the short-circuit current can be seen from the current-voltage (I-V) electrical characteristics of the cell shown in figure 3. At low intensity levels the slope of the curve at short-circuit current (V = 0) is approximately zero. Correspondingly, the short-circuit current, photoconductive current, and light-generated current (ref. 3) are the same, and the short-circuit current is linearly related to intensity level, as shown in figure 2. As the intensity level increases, the slope of the I-V characteristic curves at short-circuit current becomes noticeably greater than zero. The short-circuit current and light-generated current are not equivalent, and short-circuit current and intensity level are no longer linearly related. However, as the cell is biased into the third (or photoconductive) quadrant, the circuit current increases and asymptotically approaches the light-generated current. The change in the shape of the characteristic curve with intensity level is due to the very high circuit currents, the internal series resistance of the cell, and surface heating (or temperature) effects which occur at the

high radiant heat loads. Each of these effects contributes in some degree to altering the electrical characteristics of the cell.

An added advantage of using the solar cell as a photoconductor for radiometer purposes is that the cooling-water temperature has only a minor effect on the current. This is illustrated in figure 4, where the electrical characteristics of the cell are shown for variations in the cooling-water temperature for temperatures between 12° and 90° C at a constant intensity level of 1400 milliwatts per square centimeter. Even though the curves become more rounded as the temperature increases and the short-circuit current noticeably decreases, the measured current for a reverse bias voltage greater than 0.4 volt is essentially unchanged. The variation of the photoconductive current and the short-circuit current with the cooling-water temperature is shown in figure 5 for intensity levels of 1400 and 2800 milliwatts per square centimeter. For the temperature range from 12° and 90° C the short-circuit current changes by 10 percent at 1400 milliwatts per square centimeter and as much as 20 percent at 2800 milliwatts per square centimeter, while the photoconductive current at a bias voltage of 1 volt varies by less than 5 percent over the same temperature range. In fact, there appears to be a bias voltage at a given intensity level for which the current is independent of temperature. This point, however, has not been explored because the small temperature effect which exists at a bias voltage of -1 volt has generally been acceptable for the present application.

SUMMARY OF RESULTS

The characteristics of a conventional silicon solar cell when used as a radiometer to measure and control the intensity level of a solar simulator have been determined for intensity levels from 70 to 2800 milliwatts per square centimeter (20 solar constants). The short-circuit current is a suitable output measurement and is linearly related to the radiation intensity only for intensity levels to approximately 700 milliwatts per square centimeter (5 solar constants). For intensity levels greater than 700 milliwatts per square centimeter, it is necessary to operate the solar cell as a photoconductive device in order to obtain the desired linear relation between measured current and radiant intensity. If the cell is biased with a voltage of -1 volt, the measured current is again linearly related to the intensity level over the complete intensity range from 70 to 2800 milliwatts per square centimeter (1/2 to 20 solar constants). In addition, the measured current in the photoconductive mode is relatively insensitive to temperature changes.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 10, 1971,
114-03.

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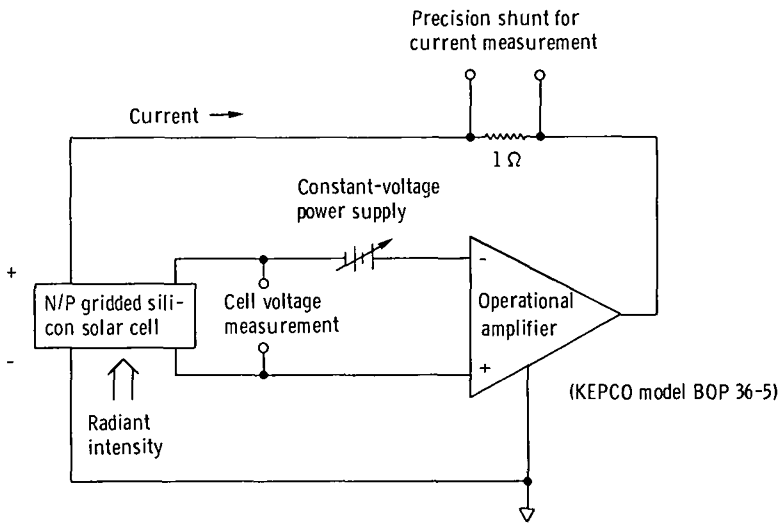

Figure 1. - Schematic diagram of electrical circuit for obtaining solar-cell electrical characteristics.

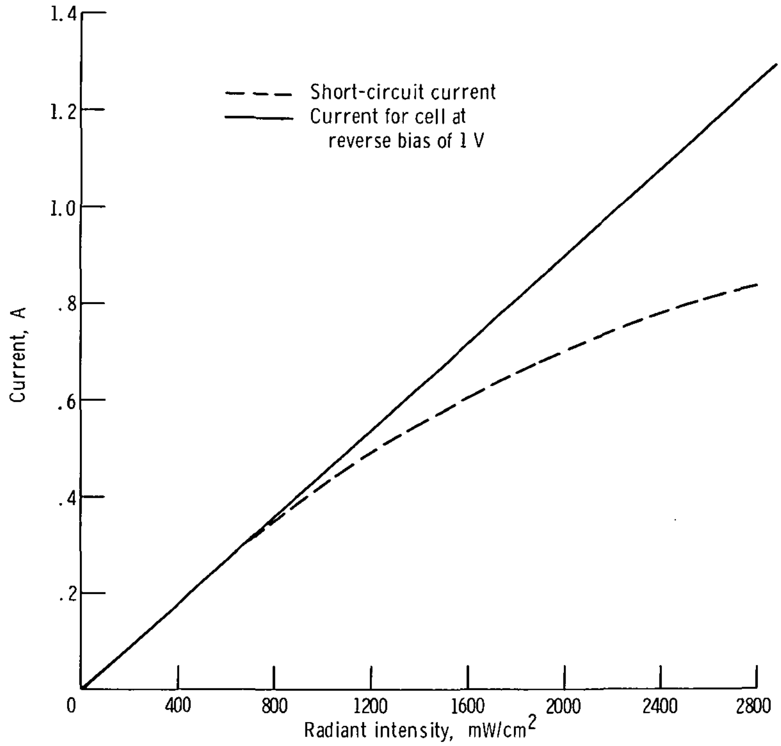

Figure 2. - Correlation of cell current and radiant intensity. Cooling-water temperature, 12^0 C.

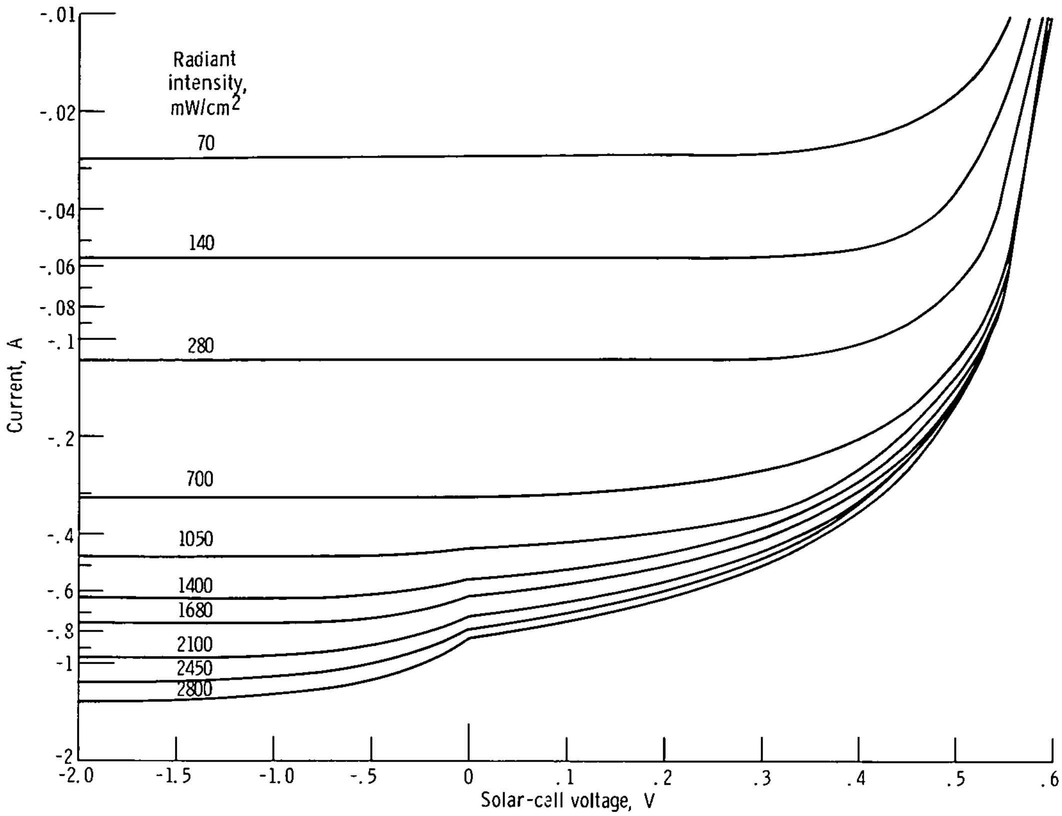

Figure 3. - Electrical characteristics of silicon solar cell. Cooling-water temperature, 12^0 C.

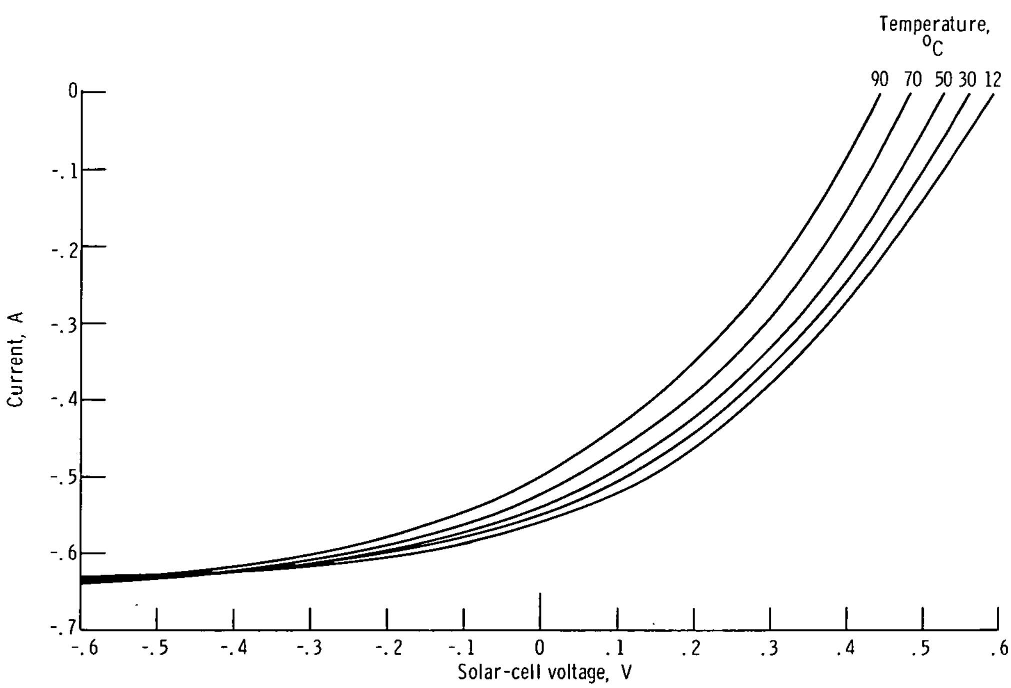

Figure 4. - Effect of temperature on electrical characteristics. Radiant intensity, 1400 milliwatts per square centimeter.

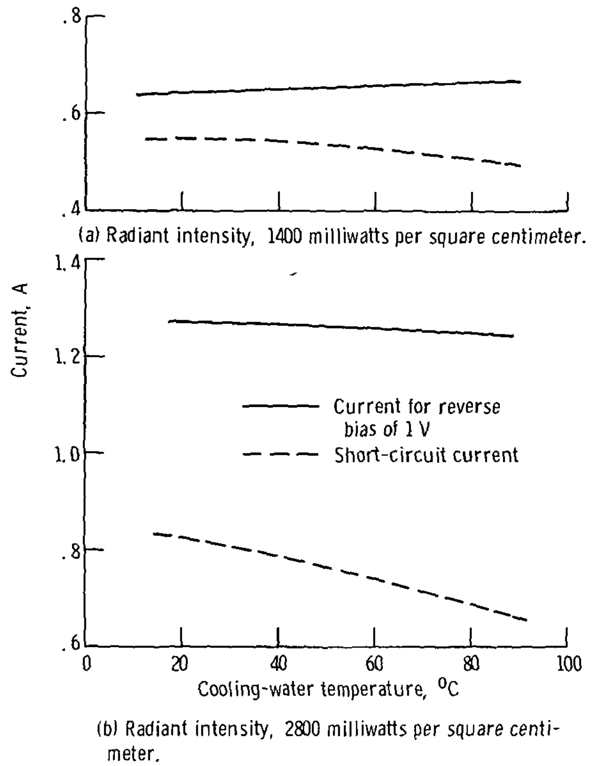

Figure 5. - Effect of temperature on cell current.

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